An Undergraduate Biomedical Engineering Curriculum – First Principles First

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abstract:

The University of Hartford established an undergraduate program in Biomedical Engineering in the early 1990s. The program is based on the philosophy that a student should first have a solid foundation in traditional engineering disciplines, followed by in-depth courses in biomedical engineering, significant off-campus experience in a biomedical facility, and design opportunities. This provides the same level of depth as the more "traditional" engineering majors as the core biomedical courses do not need to teach elementary engineering concepts. This follows the pyramid model of only teaching advanced concepts once the basics are understood, and not attempting to teach high level biomedical engineering concepts first.

Traditional undergraduate engineering education, especially in Civil and Mechanical Engineering, allows a graduate to shift among different areas of expertise over their career due to the similarity of fundamental principles. Using this approach, as well as the recent emphasis on engineering design throughout the four-year curriculum, the University of Hartford developed its undergraduate Biomedical Engineering Program. During the first two years, the program is very similar to that of Mechanical or Civil Engineering. Each student becomes strongly versed in basic engineering principles prior to enrolling in the core Biomedical Engineering courses. After mechanics and thermo/fluids the students take courses in Biomechanics and Biofluids. Bioinstrumentation is taken after two courses in Electrical Engineering. This permits the core Biomedical Engineering courses to be taught at a high level, without having to focus on basic principles. This system also permits the students to form study groups with other engineering students to widen the breadth of their exposure to engineering. In addition, students are required to take a year of Chemistry, a year of Anatomy & Physiology and at least one upper level course in Cellular Biology (or the equivalent).

introduction:

One of the major philosophical issues when designing or revising an undergraduate biomedical engineering program is when to begin teaching core biomedical engineering courses (combining both engineering and bioscience issues), and how to include more "traditional" engineering courses. Specifically, which should come first in the curriculum.

At the University of Hartford, when we established our undergraduate program in Biomedical Engineering, we first examined how the other undergraduate disciplines were taught. In all cases, general engineering principles were taught first. These included the topics of statics, dynamics, introduction to electrical engineering, and circuit analysis. The Civil and Mechanical Engineering students also were taught mechanics of materials, thermodynamics, and fluid mechanics. After these courses, the various disciplines then split off into upper level courses during which the students are taught more in depth concepts using the framework established in earlier courses. In this manner, more advanced concepts can be focussed upon without extensive time being taken to teach basic concepts applicable to many fields.

The second issue that was considered was one of focus for the new program. The core faculty came from Mechanical and Civil Engineering backgrounds, and had foci in the structural and fluids areas of Biomedical Engineering. In evaluating the existing programs, it was felt that the new program had many aspects in common with Mechanical Engineering, especially as related to mechanics of materials, structures, and fluids. Although electrical engineering topics are critical to a biomedical engineering program and would play an important role in the new program, this was not planned as a primary focus of our program.

The third issue in our philosophy was the direction we felt our graduates might take upon graduation. As with other, more traditional, majors, we desired that our graduates would not be "locked-in" to a single discipline for seeking either a job or entry into graduate programs. A great strength of engineers in general is the ability to shift career focus, since most engineering topics have similar basic equations and approaches. We therefore had a desire to present our students with enough basic engineering topics to extend their ability to function as engineers beyond that of only biomedical engineering.

Using the above philosophical components, it was decided that all our students should be taught the basic engineering curriculum common to the older disciplines first, and that specific biomedical engineering courses would be developed which would add depth and specificity to this knowledge. Basic concepts of engineering would thus not have to be taught during these courses and subsequently the biomedical engineering courses could be taught at a higher intellectual level.

In evaluating our philosophy and the existing curricula in the college, it was decided that the Mechanical Engineering curriculum was already close to what we desired for our undergraduate students. The upper level courses, which present Mechanical Engineering students with in-depth knowledge in the field, were replaced with biomedical engineering specific courses. To prepare students for the biological aspects of the core courses, a year of Anatomy and Physiology was also required of all biomedical engineering students. To more fully prepare students for a career in biomedical engineering, two senior level courses were developed to permit students to work in clinically based facilities external to the university and acquire first hand experience in the field.

current program structure:

During the years since the inception of the program, a number of changes have been made to the curriculum to address the changing world of Engineering in general, and Biomedical Engineering in specific. Some of these changes have been brought about due to changes across the college of engineering, some due to the changing nature of Biomedical Engineering in the region, and some due to the changes in program outcomes as dictated by the changes in ABET philosophy. In the sections below, the current program will be described.

The basic philosophy of the program may be represented by a pyramid (Figure 1): the base is established with core courses both in and outside of engineering, the middle section builds on the fundamentals with in-depth courses in Biomedical Engineering and other topics which assume a completion of the core basics, and an ultimate section of senior courses during which the student brings together aspects of entire undergraduate education.

A new college-wide design philosophy has established a design experience that stretches throughout the undergraduate years. This begins with projects during the freshman engineering courses, and continues with college-wide design experiences during the sophomore and junior years. The culmination of this design experience is to be found within the two senior capstone courses during which the student works in off-campus facilities, and a senior design project that may be carried out in the Biomedical Engineering Laboratory on-campus.

Figure 1 shows the basic pyramid of the program. During the freshman year and the first term of the sophomore year all engineering students are taught the basic science and math skills required for their engineering courses. They are also taught the programming and graphic (drawing and CAD) skills currently required of all engineers in the major disciplines. As part of the colleges ongoing efforts to incorporate engineering and design at all levels of undergraduate education, the students take two engineering courses: “Principles of Engineering”, and “Principles of Engineering Design”.

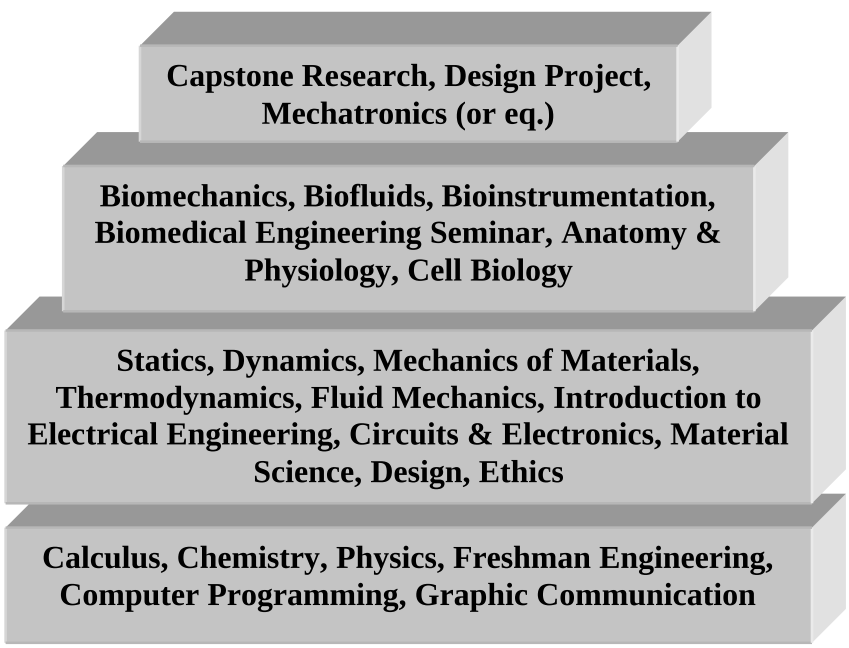

Figure 1. Programmatic Pyramid

The second portion of the pyramid base is formed by the linchpins of traditional Mechanical Engineering and Civil Engineering: Statics, Dynamics, Mechanics of Materials (with a separate but related laboratory course), Material Science, Thermodynamics, Fluids, Introduction to Electrical Engineering, and Circuits & Electronics. These courses are taken with students from the other disciplines, in order that the Biomedical Engineering students are held to the same level of expertise as those from the traditional majors. In addition, Engineering Design is continued with “Engineering by Design”, during which Biomedical Engineers are placed in teams with students from the other disciplines to work on projects developed by external mentors. There is also a strong linkage to ethics via a concurrent course.

The middle (or depth) section of the pyramid is formed by the core courses Biomechanics, Biofluids, Bioinstrumentation, and two terms of Biomedical Engineering Seminar. Each course begins with the assumption that the students are familiar with the basics of the topic. Biomechanics assumes a knowledge in Statics, Dynamics, and Mechanics of Materials. Therefore, topics such as bone mechanics and joint kinematics can be discussed without extensive time being spent teaching stress and motion fundamentals. In Biofluids, basic Thermodynamics and Newtonian fluids concepts are assumed. Non-Newtonian blood models can therefore be introduced near the beginning of the term, and the interaction of fluids properties and the mechanics of vessel walls can be discussed with little introduction. Bioinstrumentation can focus on the electronics used in the health professions with the assumption that the students are already familiar with basic concepts of circuit design and analysis. The two-course sequence of Biomedical Engineering seminar (Fall Sophomore and Junior years) is designed to acquaint students with the issues and ethics of the subject, along with the variety of research opportunities afforded biomedical engineers. Outside professionals are invited to present their research interests, often leading to senior capstone research positions for the students

The above section is the most critical of the program. Since the students arrive with knowledge of the fundamentals of each topic, these courses can be taught at a level often reserved for early graduate level courses. The overriding philosophy is that the students are taught how to use engineering concepts in evaluating the human body. If it was necessary to also teach these basic concepts during each course, most of the mathematically in-depth topics would have to be left out, and the courses would revert to survey-style courses. As this is not the manner in which other disciplines (such as Mechanical, Civil or Electrical Engineering) are taught, it was felt that this would be the best model to follow.

In addition to the engineering courses, this section of the pyramid is where the students become familiar with the biological concepts critical to the profession. All students are required to take a year of Anatomy and Physiology with the Biology and other health profession students, along with Cell Biology (or equivalent). Premed students are also required to take a year of Organic Chemistry.

During the junior year, all engineering students also continue with design issues, including a course in engineering practice. This course is linked to a specific Humanities course designed to further investigate the interaction of the engineer with the world as a whole.

The final section of the pyramid, taken during the senior year, is the culmination of the process and allows the Biomedical student to utilize the knowledge from the previous courses. This process is similar to that of the older programs in the college in the Design Project course, but varies with the Capstone Research I and II courses. In the latter two courses, each student is required to work in external clinically related facilities for two course equivalents. The first course is designed to afford the student the opportunity to see what a clinically related facility is like, and the second allows the student to consolidate their education and assist a laboratory as a biomedical engineer on a project. To ensure that each student has an ABET-level of design experience at the senior level, each student is required to complete a design project during their senior year under the direction of the Biomedical Engineering faculty.

program outcomes:

While it is difficult to assess the outcome of this style of curriculum in comparison to programs teaching biomedical engineering courses first, there are anecdotal outcomes to report. External supervisors of our senior students (during capstone off-campus research) have noted that the students had backgrounds comparable to Mechanical Engineering students working in the same laboratories. Other supervisors who also work with graduate students in biomedical engineering have noted the strong background of our students.

The feedback from our alumni have noted the strong level of their general engineering background as compared to their peers in biomedical engineering and related disciplines. These students have either entered the workplace directly or continued on to graduate programs.

It is still too early to make blanket judgements as to the benefit of teaching engineering fundamentals first. In fact, without a parallel study at a single institution this question may remain unanswered. It should, however, be noted that the traditional majors (Mechanical, Electrical, Civil and Chemical Engineering) have in general taught basic engineering fundamentals first, then the specialty topics. This has been a long proven model, and is the one we chose to follow.

conclusions:

As the field of Biomedical Engineering matures and changes, our graduates must be able to adjust their outlooks and areas of expertise. An engineer well grounded in the fundamentals of the field is better equipped to do this.

Teaching engineering fundamentals with the other engineering majors allows the Biomedical Engineering students to understand the principles of the field without having to spend significant amounts of time during the program specific courses. The interaction of the Biomedical Engineering students with the other engineering students during the formative first years gives them a sense of identity as engineers first, then biomedical engineers. This is important, as Biomedical Engineering is a bridging discipline, where the principles of engineering are brought to bear on issues relating to the body.

We believe our approach to give our graduates a wide range of career paths relating to work or graduate school. They are prepared to bring both a breadth and depth of knowledge to bear on their career paths, even if those paths may change as they progress through the years. In addition, this style of teaching allows for a great deal of uniformity among engineering programs and incorporates the students into the general engineering student population during the first formative years at the university.

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